darkside
two-phase argon TPC for Dark Matter Direct Detection

The DarkSide Program

XVI LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS
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DarkSide Collaboration

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INFN Laboratori Nazionali del Gran Sasso – Assergi, Italy
Università degli Studi and INFN – Genova, Italy
Università degli Studi and INFN – Milano, Italy
Università degli Studi Federico II and INFN – Napoli, Italy
Università degli Studi and INFN – Perugia, Italy
Università degli Studi Roma Tre and INFN – Roma, Italy
Jagiellonian University – Krakow, Poland
Joint Institute for Nuclear Research – Dubna, Russia
Lomonosov Moscow State University – Moscow, Russia
National Research Centre Kurchatov Institute – Moscow, Russia
Saint Petersburg Nuclear Physics Institute – Gatchina, Russia
KINR, NAS Ukraine – Kiev, Ukraine
Augustana College – SD, USA
Black Hills State University –SD, USA
Fermilab – IL, USA
Princeton University – NJ, USA
SLAC National Accelerator Center – CA, USA
Temple University – PA, USA
University of Arkansas – AR, USA
University of California – Los Angeles, CA, USA
University of Chicago - IL, USA
University of Hawaii – HI, USA
University of Houston – TX, USA
University of Massachusetts – MA, USA
Virginia Tech – VA, USA

The DarkSide program at LNGS

A scalable technology for direct WIMP search:
2-phase low background argon TPC

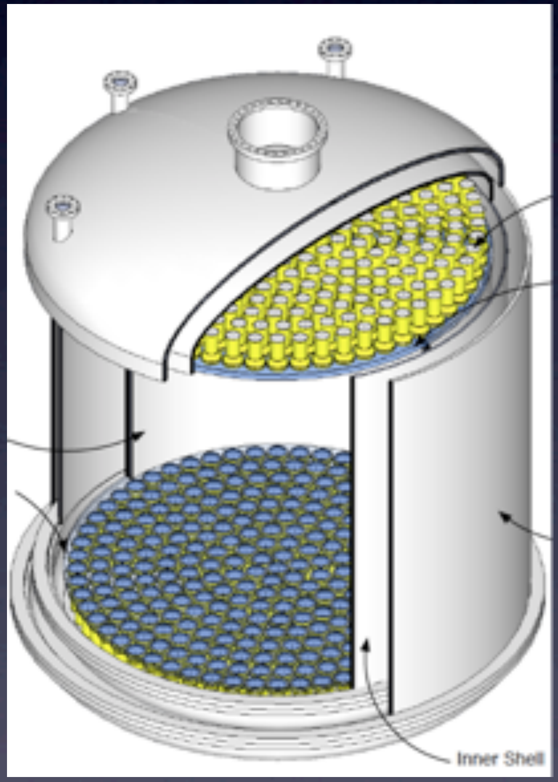
DarkSide-10

technical prototype
no DM goal

DarkSide-50

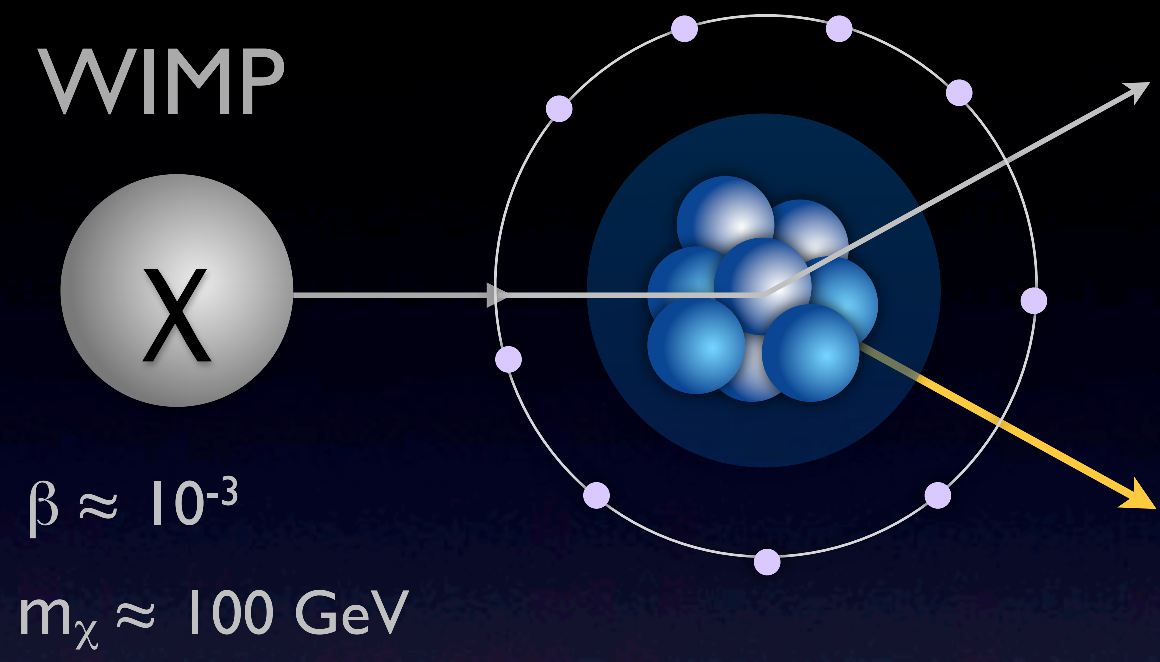
sensitivity
10^{-45} cm^2

DarkSide-G2



sensitivity
10^{-47} cm^2

WIMP direct detection requirements



$\chi N \rightarrow \chi N$
elastic scattering off nuclei

Low energy nuclear recoils (< 100 keV)
Low rate (~1 event/ton/yr for $\sigma=10^{-47}$ cm^2)

⇒ Maximize detector sensitivity

⇒ Background avoidance, rejection, measurement

Detector designed for unambiguous discovery

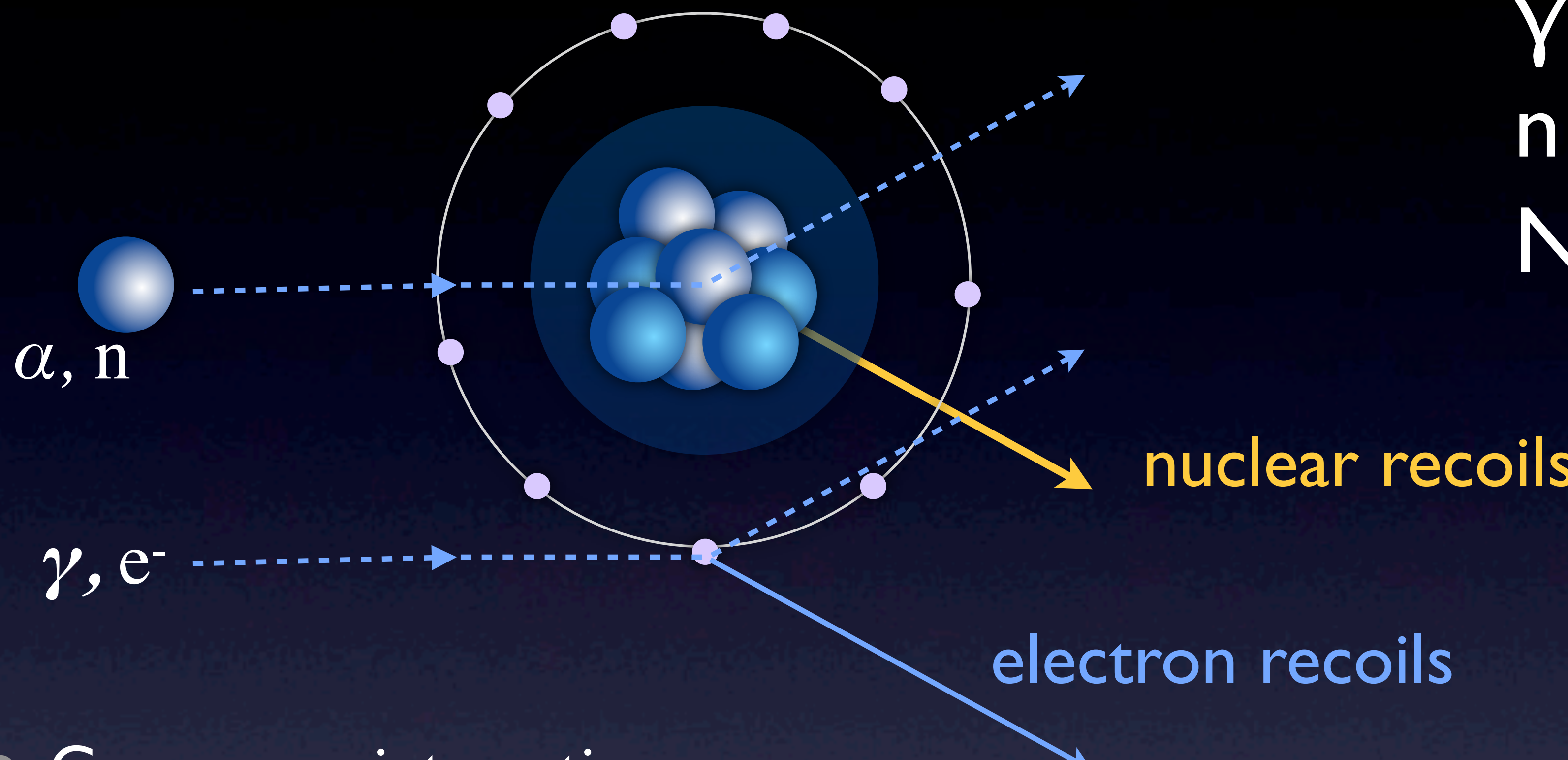
Background

from natural radioactivity:

$\gamma\, e^- \rightarrow \gamma\, e^-$

$nN \rightarrow nN$

$N \rightarrow N' + \alpha, e^-$



- Gamma ray interactions:

  mis-identified electrons mimic nuclear recoil signals

- Neutrons:

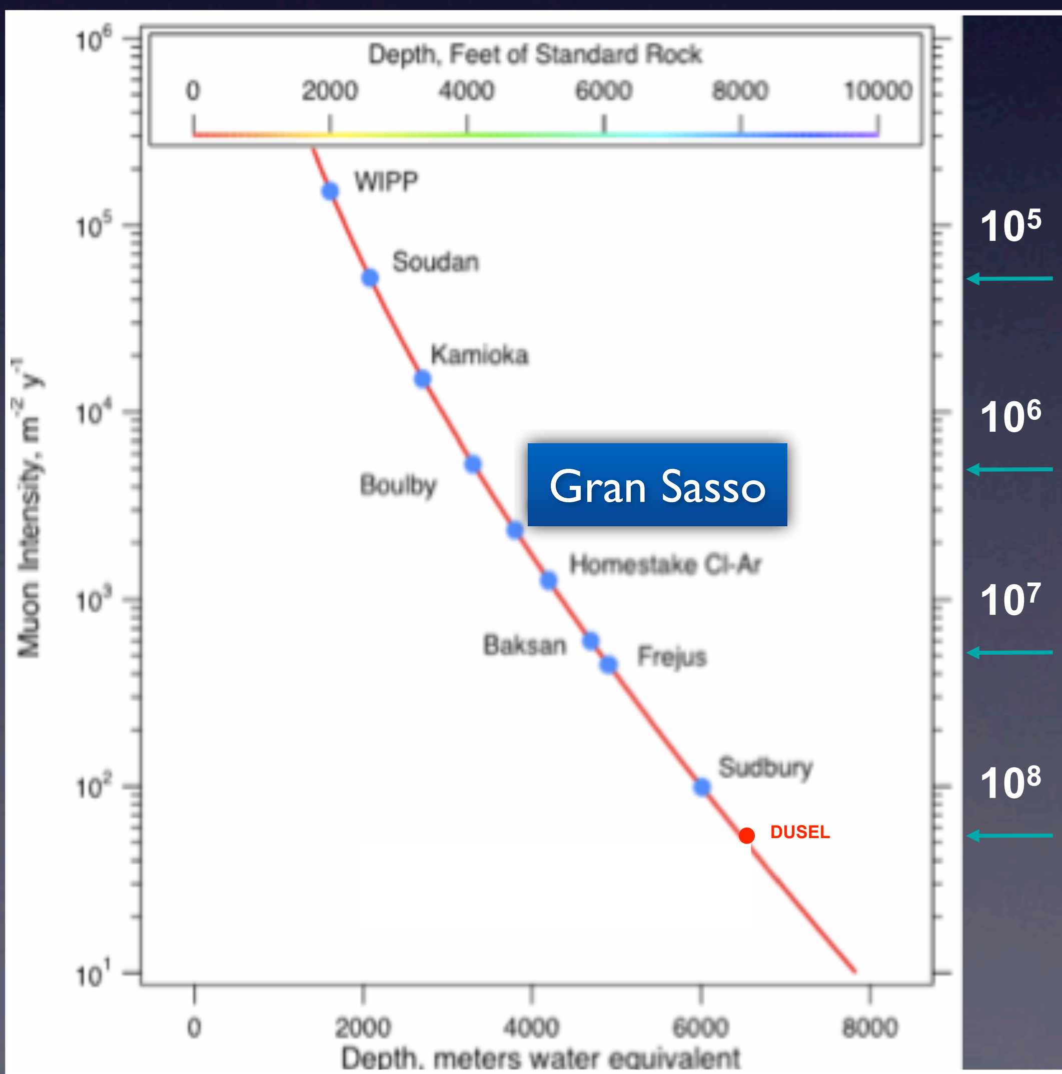
  (α,n), U, Th fission, cosmogenic spallation

- Contamination:

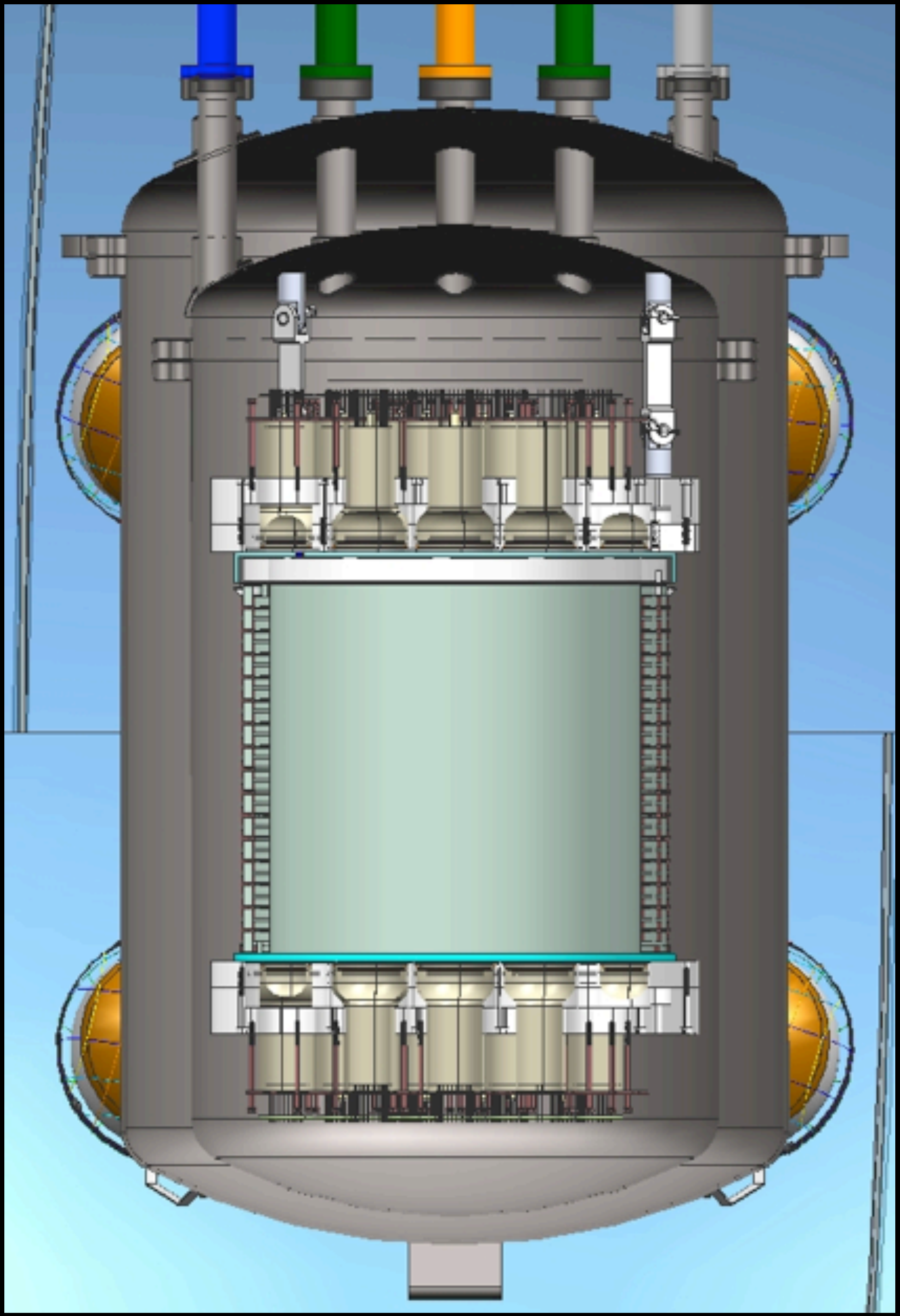
  ^{238}U and ^{232}Th decays, recoiling progeny mimic nuclear recoils

Underground labs

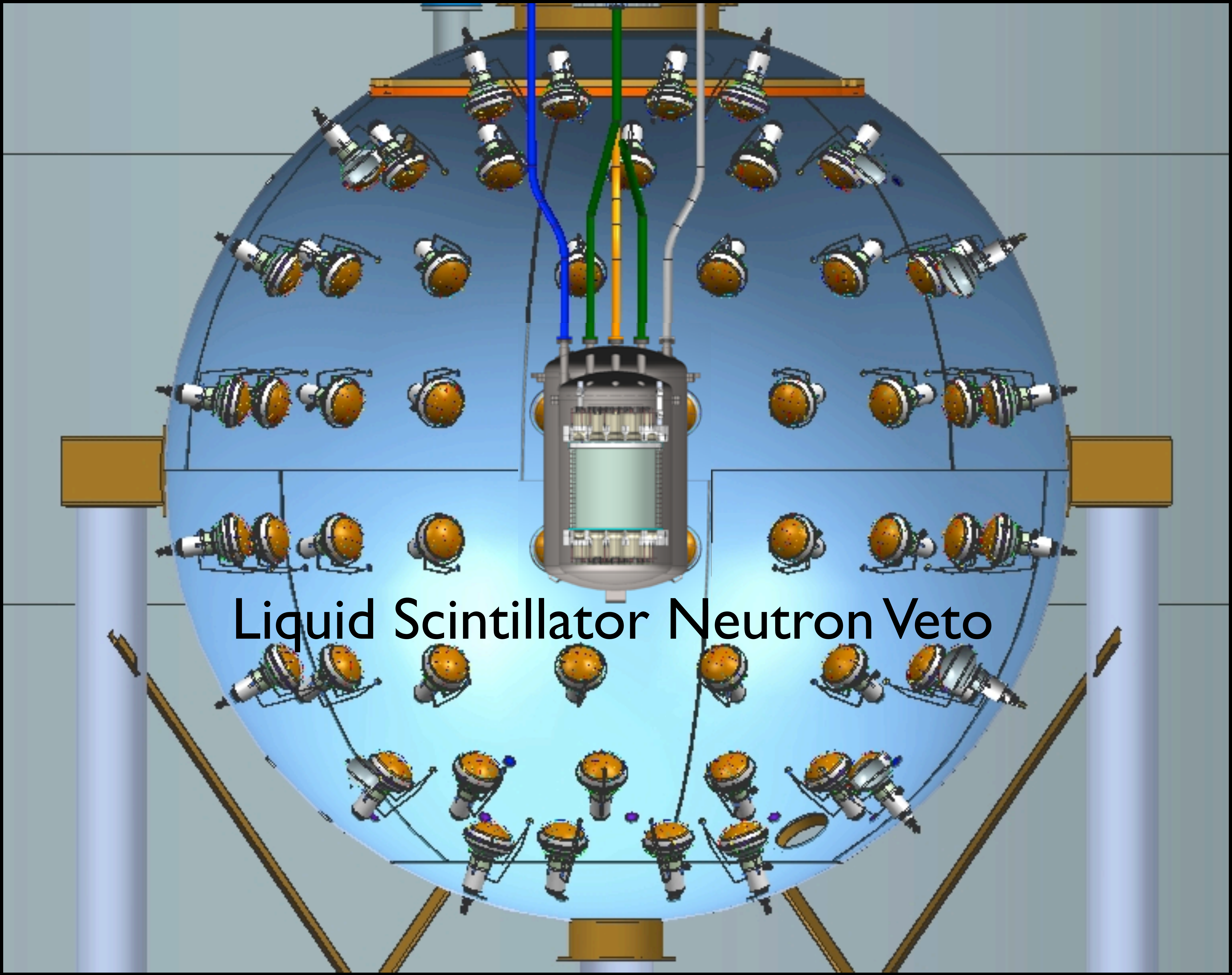
reduction of muon flux by:

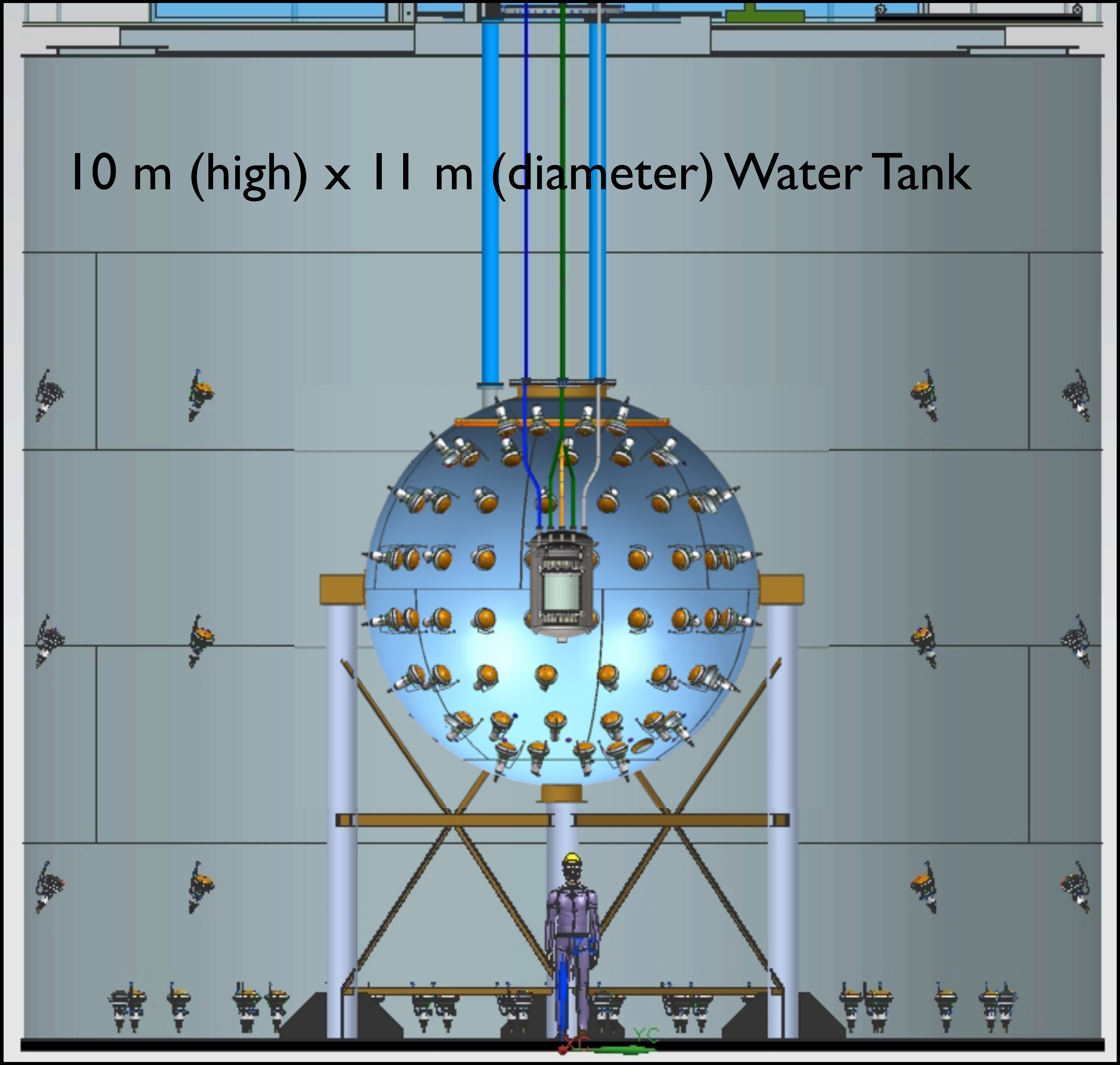


Liquid Argon TPC,
within a neutron veto,
within a muon veto,
under a mountain



Liquid Argon TPC & Cryostat


Liquid Scintillator Neutron Veto


10 m (high) x 11 m (diameter) Water Tank

Argon as target for DM detection

- Bright scintillator: Light Yield ~ 40 γ/keV and very transparent to its own scintillation light
- Relatively abundant (1% in atmosphere) and easy to purify
- Large mass detectors → scalability + self-shieding
- Possible scaling to multi-ton detectors: need to suppress ^{39}Ar
  - Underground argon (UAr): ^{39}Ar depletion factor >150
- Very powerful rejection capability for electron recoil background

^{39}Ar beta decays with 565 keV endpoint, with half-life 269 years

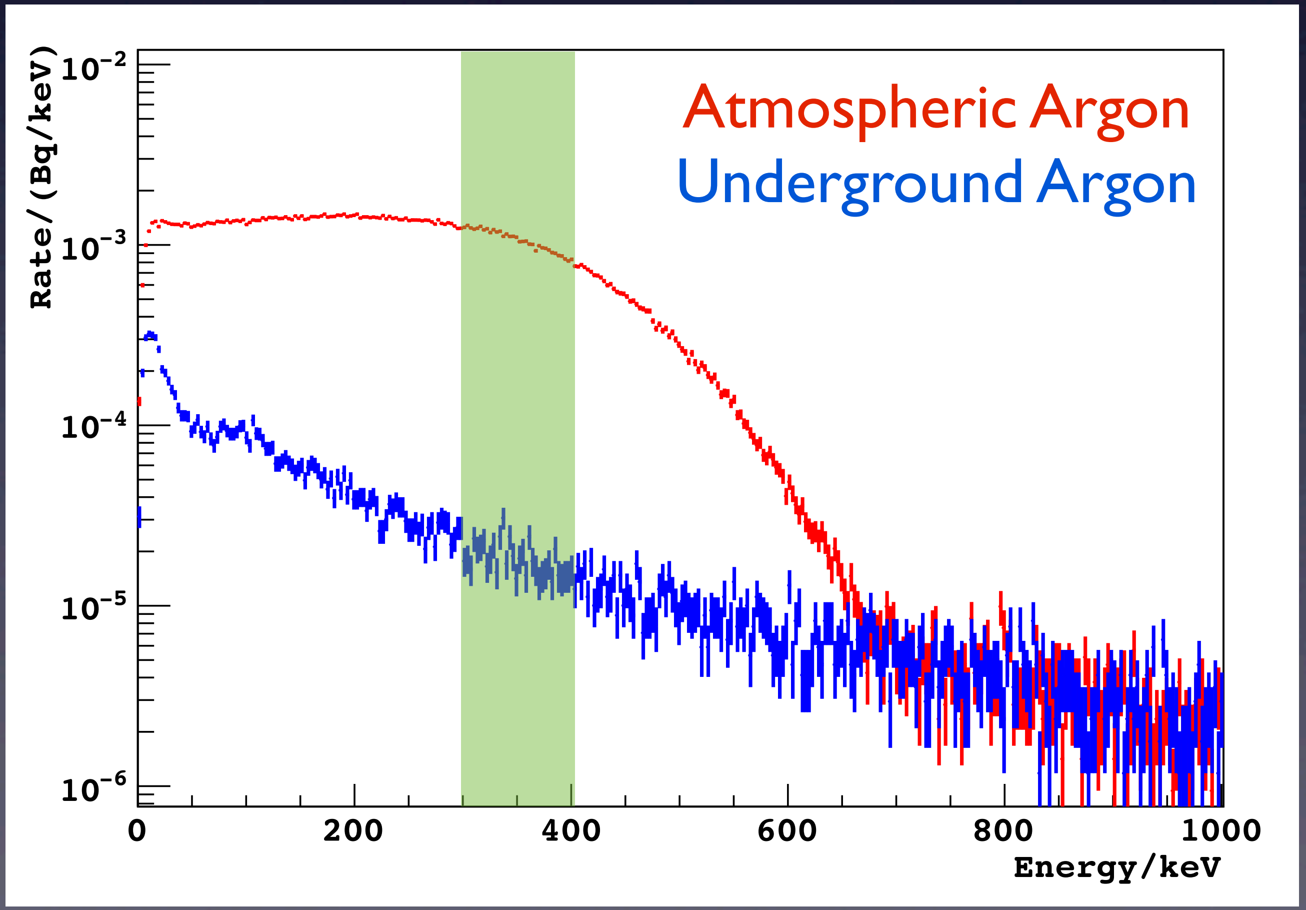
^{39}Ar production supported by cosmogenic activation via ^{40}Ar(n,2n)^{39}Ar

^{39}Ar activity in atmospheric argon ~1 Bq/kg

UAr ^{39}Ar activity <6.5 mBq/kg

150 of 150 kg collected

J.Xu et al. arXiv:1204.6011



Two Phase Argon TPC

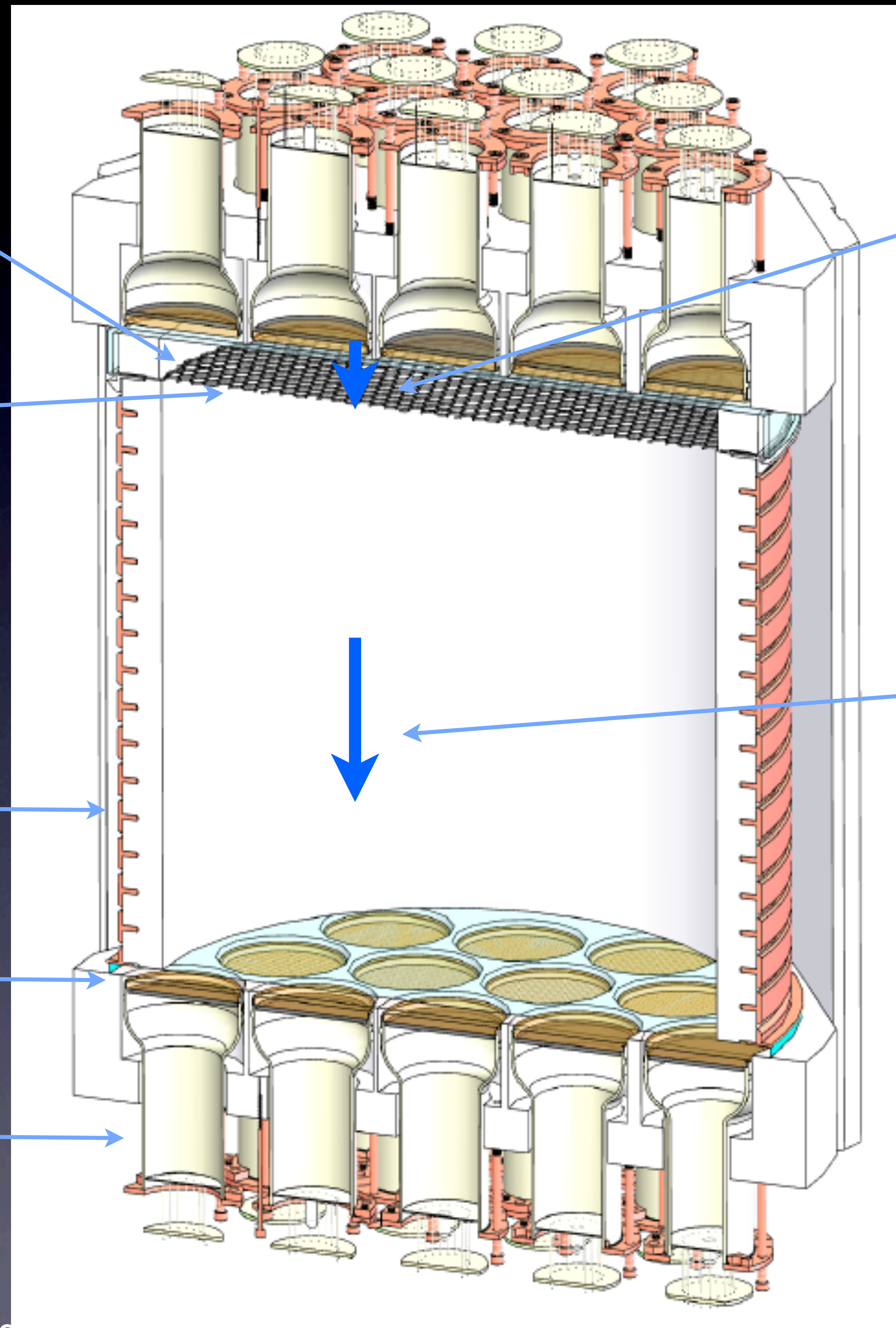
TPB+ITO coated diving bell (anode)

extraction grid

field cage

ITO coated window (cathode)

photosensors



Extraction Field (~3kV/cm)

Gas phase

Drift Field (~1kV/cm)

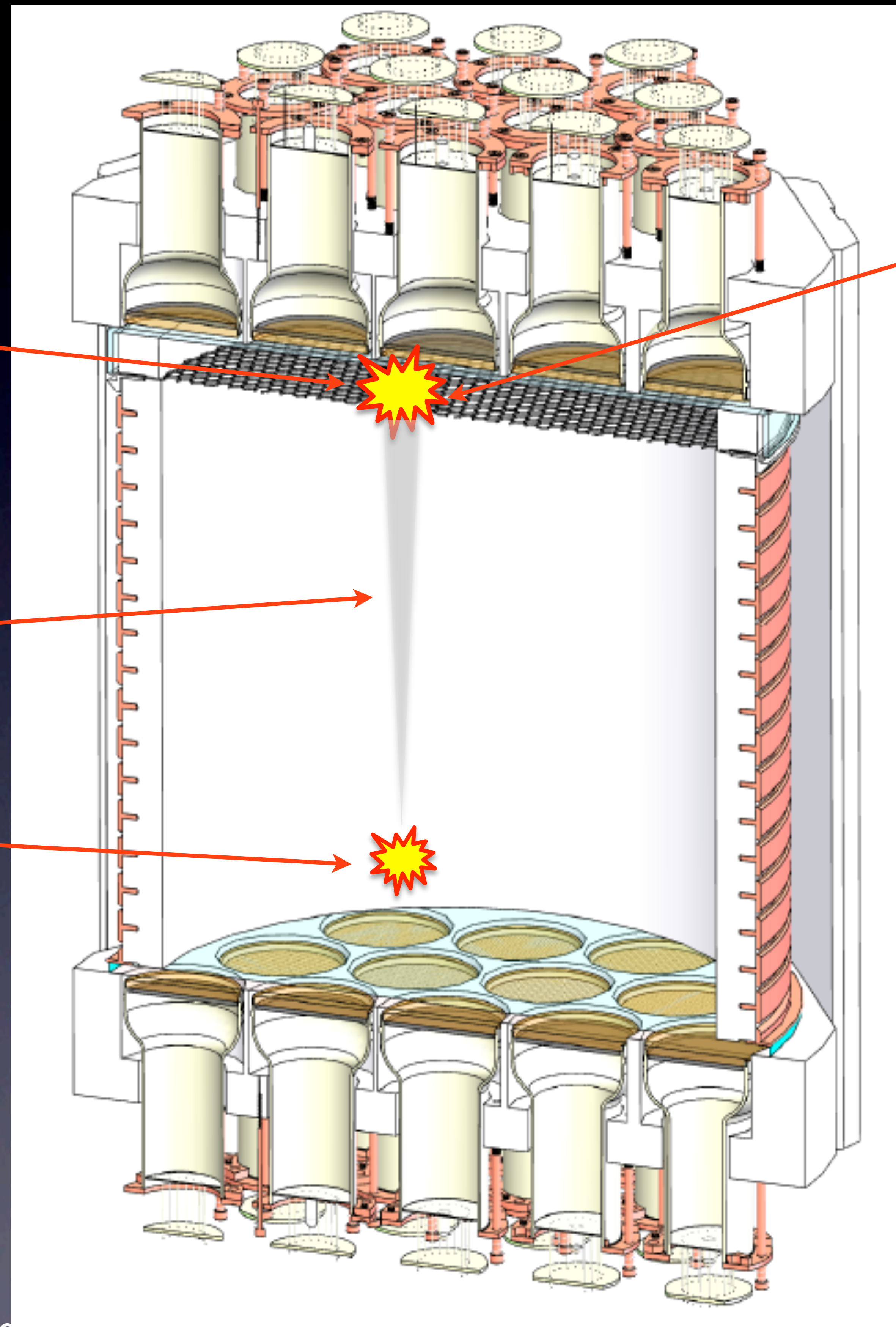
Liquid phase

Two Phase Argon TPC

Electro-
luminescence
“S2” Light

Drift charge

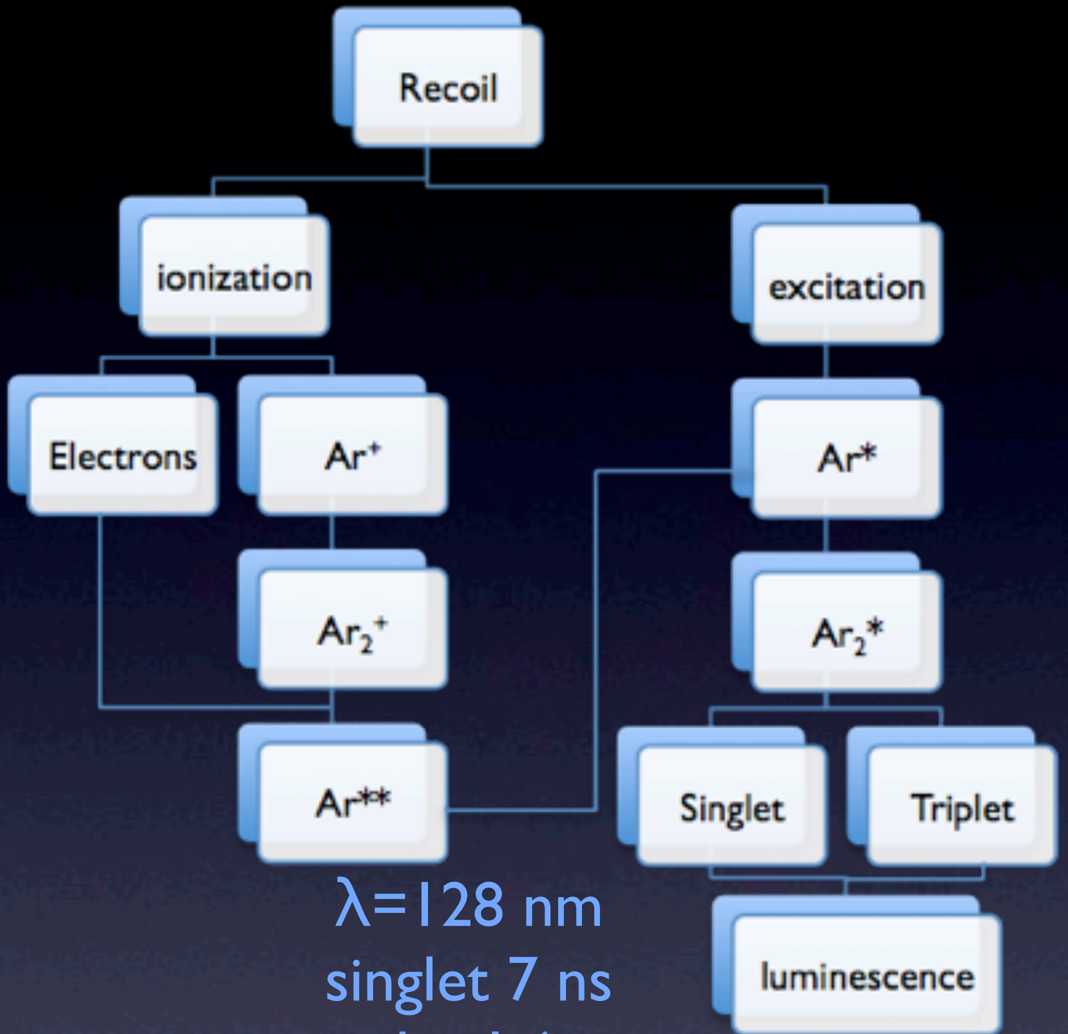
“S1” Scintillation
Light



Pattern of S2 light
gives x-y position
(~1cm resolution)

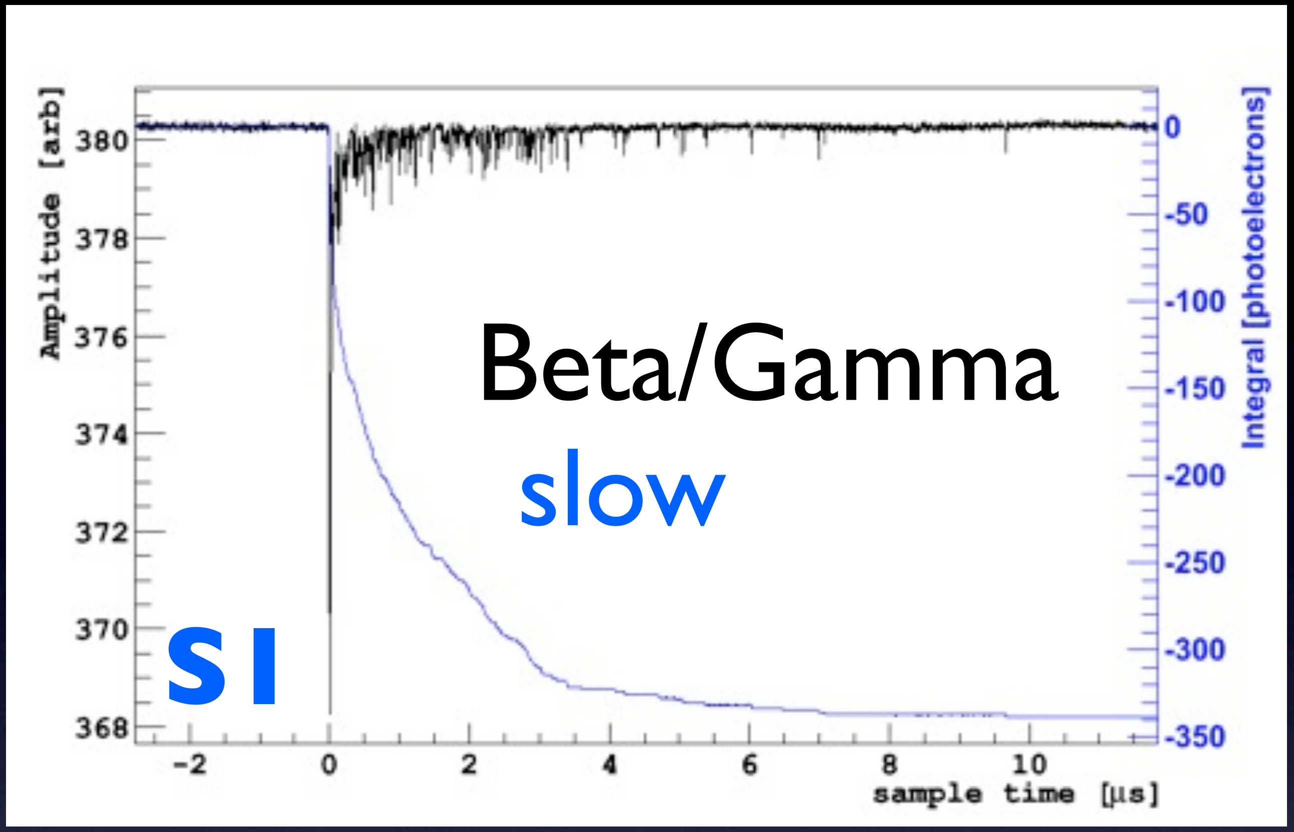
Time difference
between S1 and S2
gives z position
(few mm resolution)

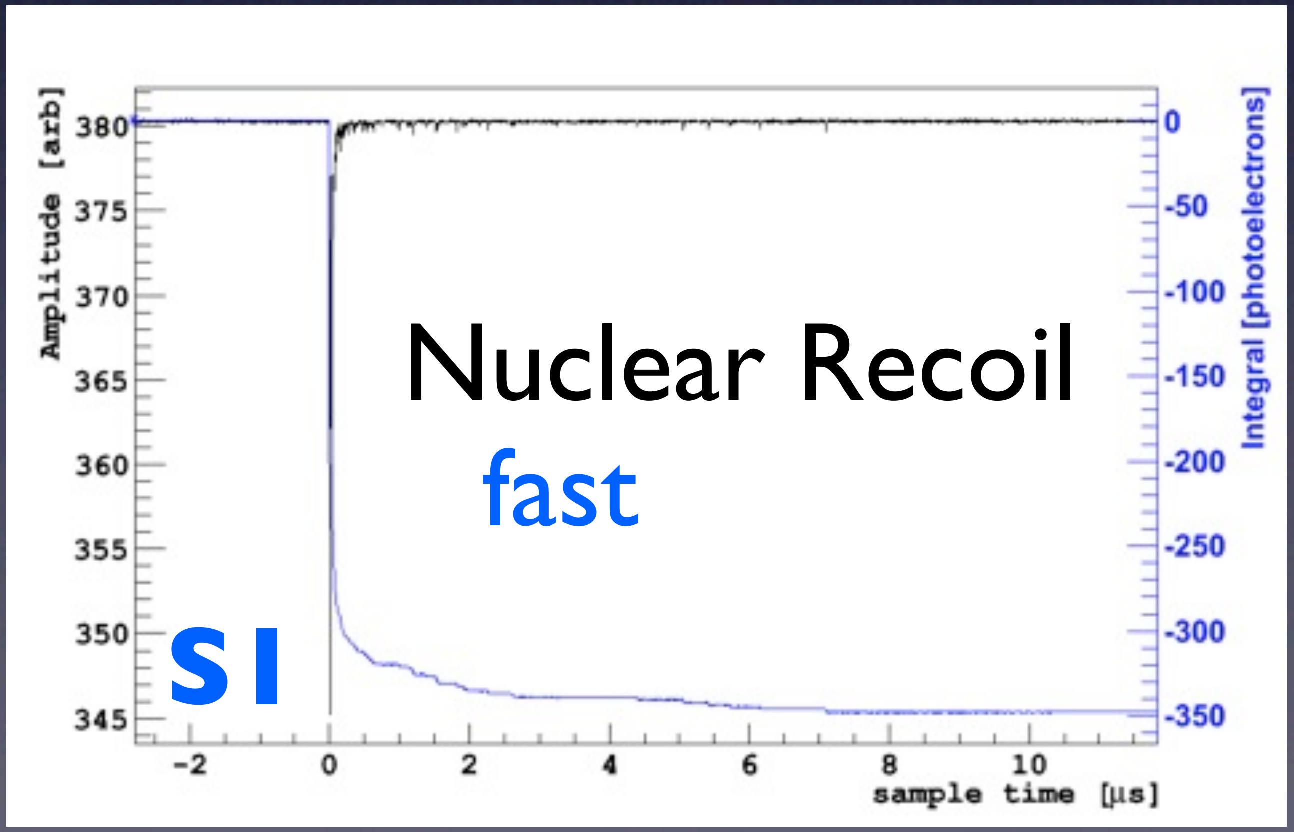
Background Discrimination: S1 Pulse Shape



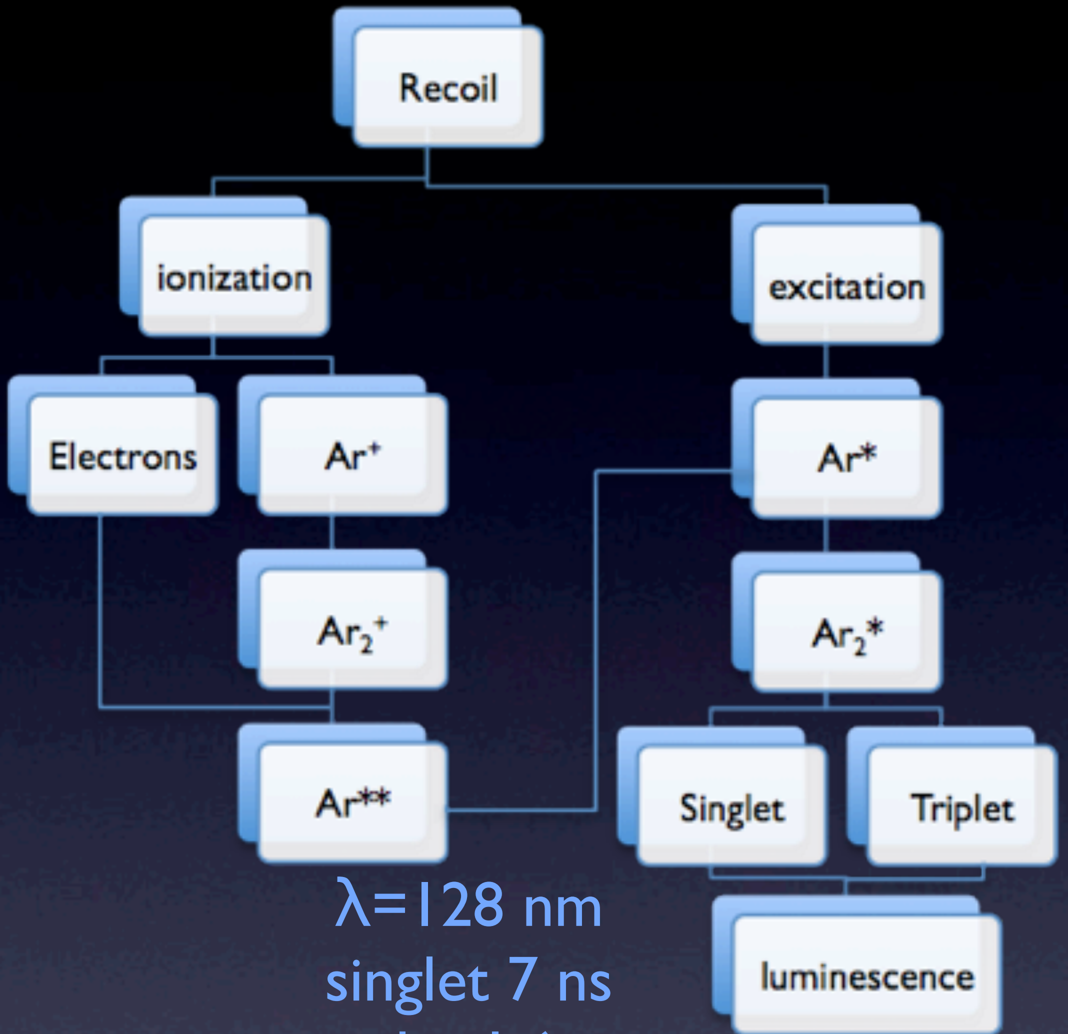
λ=128 nm
singlet 7 ns
triplet 1.6 μs

The ratio of light from singlet (~7 ns decay time) and triplet (1.6 μs decay time) depends on ionization density





Background Discrimination: S1 Pulse Shape



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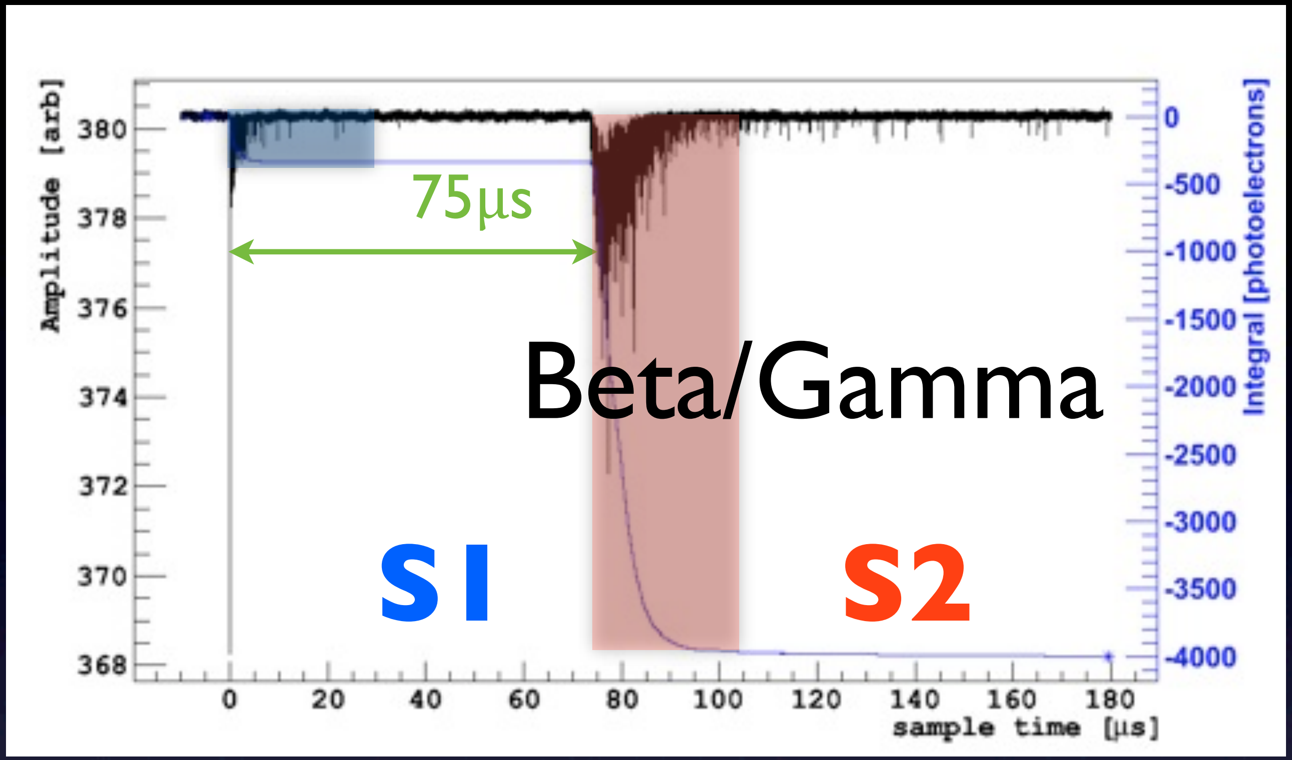
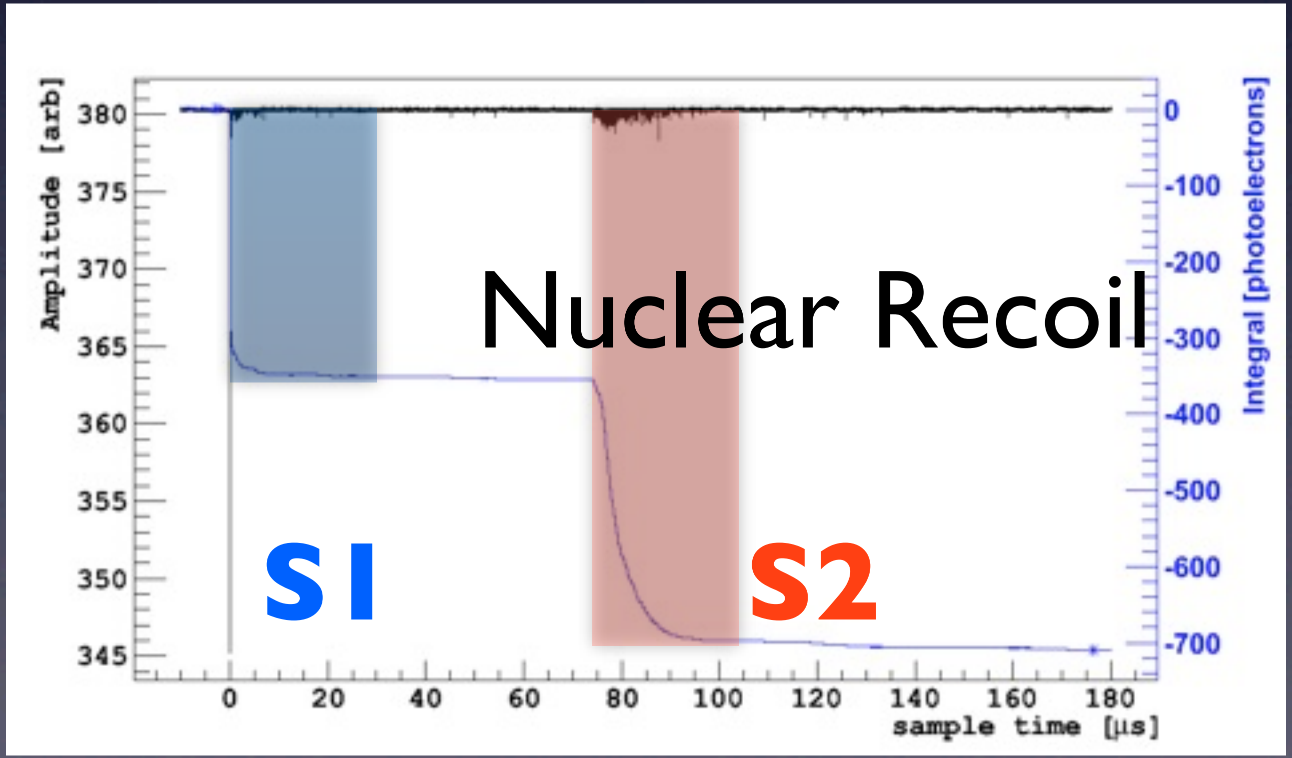




The recombination probability (and hence the ratio of S2:S1 light) also depends on ionization density

LAr TPC Background Discrimination

Shape of scintillation signal S1 (PSD)

Electronic and nuclear recoil events have different singlet to triplet ratio

➡ Rejection factor $\geq 10^8$ for > 60 photoelectrons

WARP Astr. Phys 28, 495 (2008)

Ratio between Ionization and Scintillation (S2/S1)

Electronic and nuclear recoil events have different energy sharing

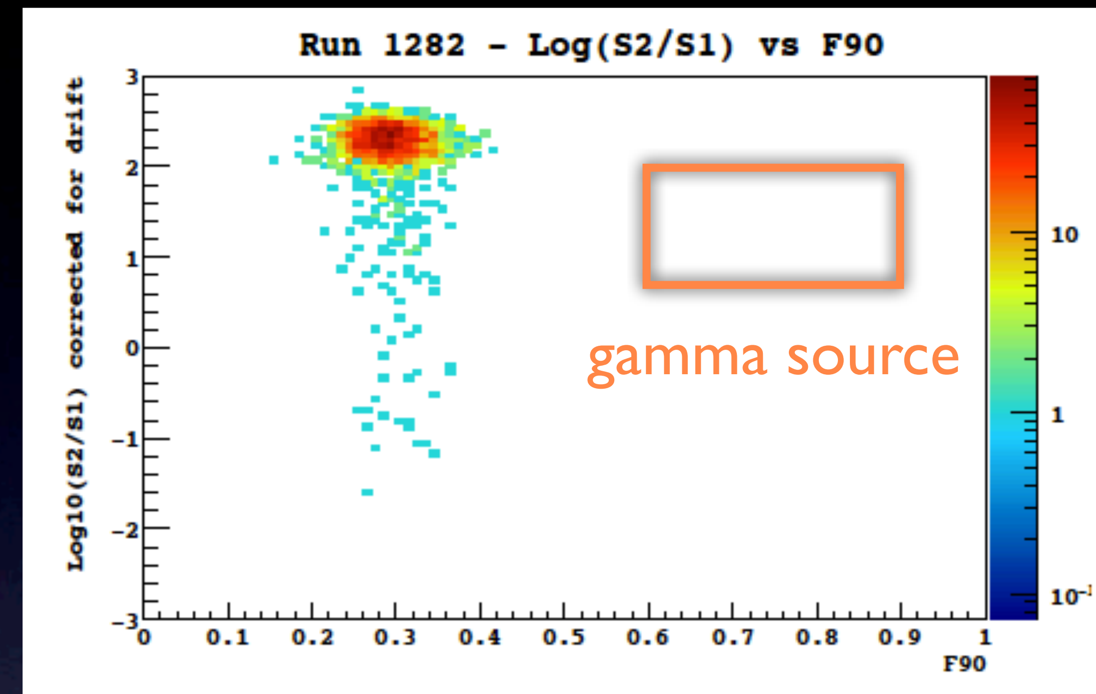
➡ Rejection factor $\geq 10^2$-10^3

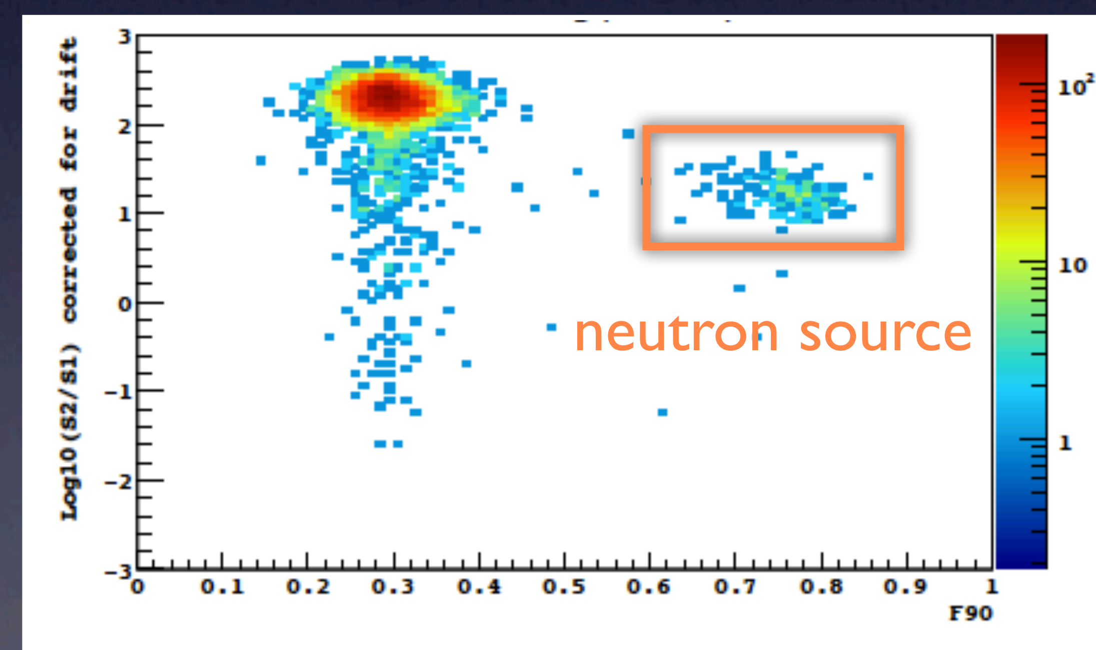
Benetti et al. (ICARUS) 1993; Benetti et al. (WARP) 2006

3D localization of the event

Allows for identification of surface bkgs (fiducialization)

0.7kV/cm drift, 2.7kV/cm extraction





➡ expect $>10^{10}$ total electron/gamma background rejection

DarkSide-10 TPC

- Two phase Argon TPC prototype used to test new technological solutions for the DS program
- 10 kg active mass of Atm LAr + passive water veto
- 7 (top) + 7 (bottom) R11065 HQE Hamamatsu 3” PMTs
- ϕ 20 cm × 20 cm drift
- 2 cm gas gap

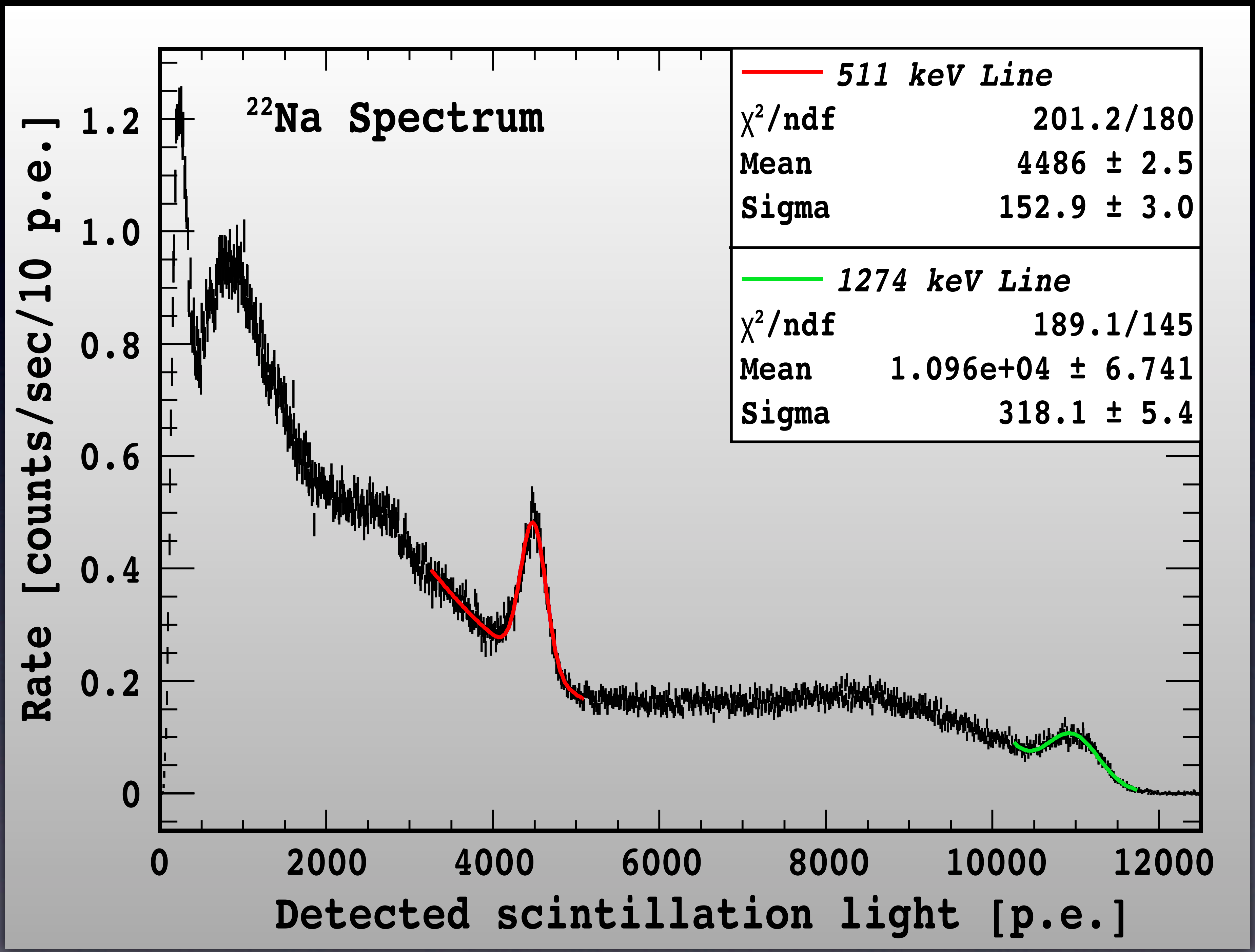
Not physics capable (a fraction of a neutron per day due to cryostat, feedthroughs, and shield)

✓ Demonstrate high LY

✓ Stable HHV system at 36kV

✓ Study discrimination, purity, electric field settings, levelling

DS-10 @ LNGS: Light Yield in single phase mode



T.Alexander et al. arXiv 1204.6218

LY=8.78 ± 0.01 p.e./keVee @ null field, gas pocket present

DarkSide-50 TPC

- 50 kg active mass of UAr
- 19 (top) + 19 (bottom) R11065 HQE Hamamatsu 3” PMTs
- ϕ 36 cm × 36 cm drift
- Lateral walls made of high reflectivity polycrystalline PTFE
- All inner surfaces coated with TPB
- Fused silica diving bell (top) and window (bottom) in front of the PMT arrays coated with ITO.

Designed to provide an extremely high light yield, decreasing the detection energy threshold

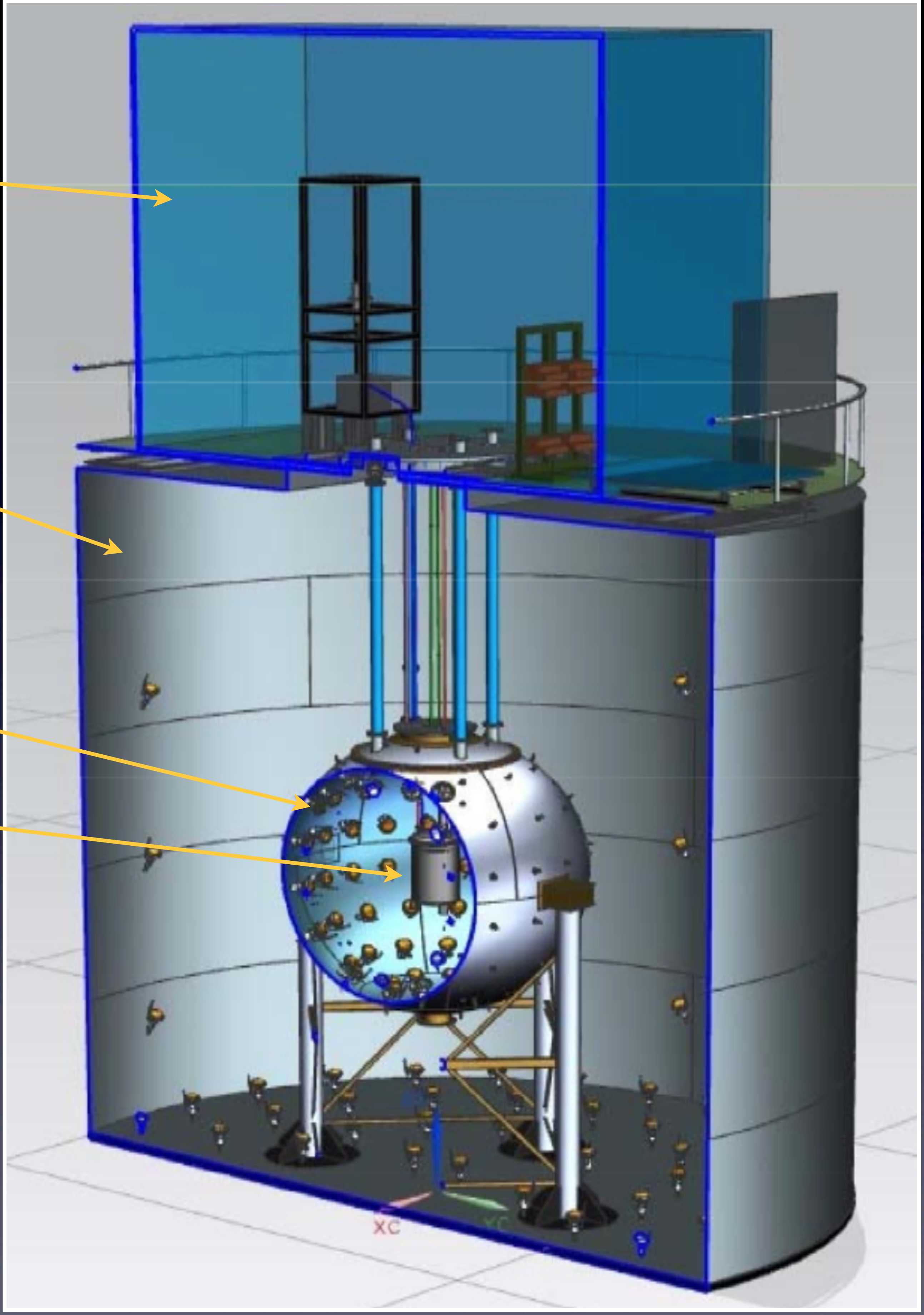
Radon-free clean assembly room
$\leq$ 30 mBq/m³ in >100 m³
(CRH)

μ veto and cosmogenic neutron passive shield
1000 ton water Cherenkov
(Borexino CTF)

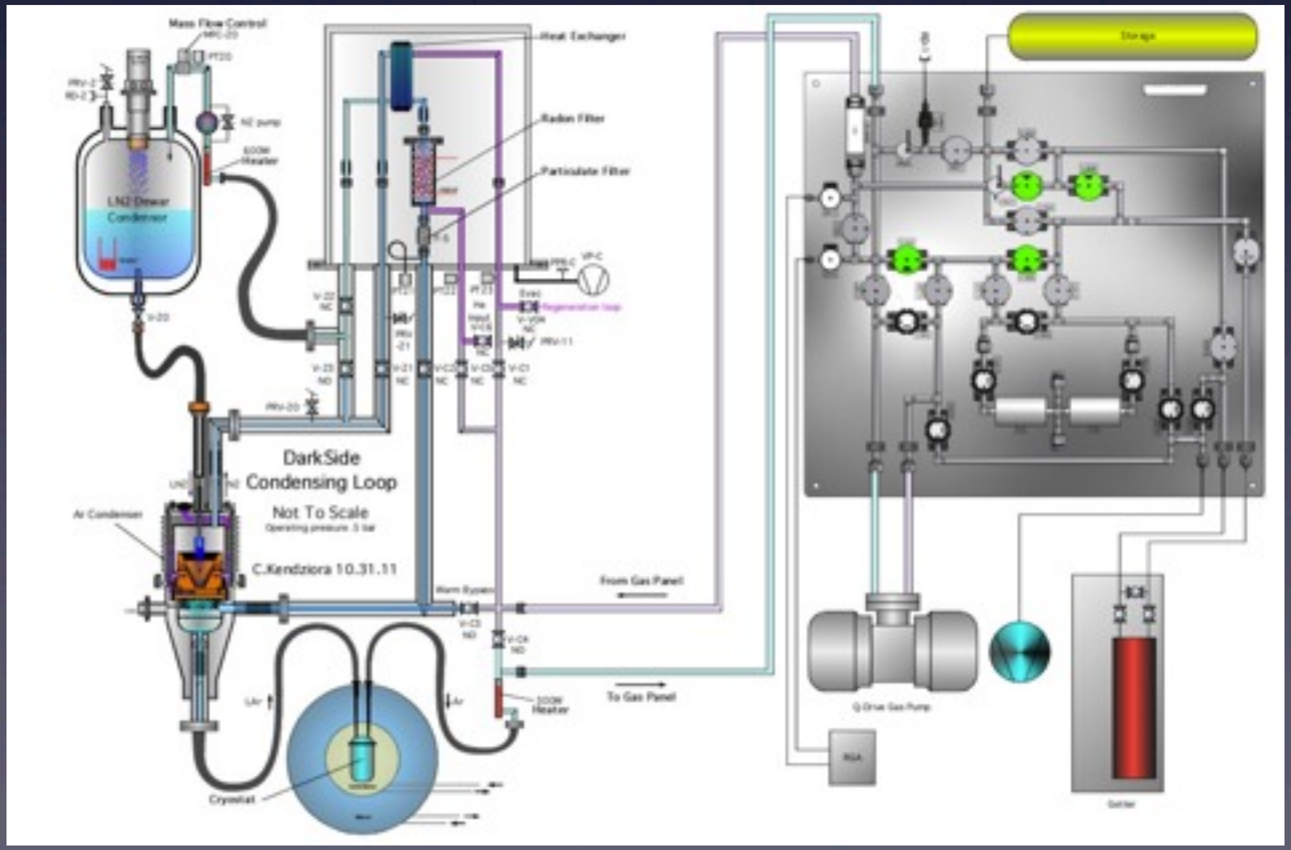
Radiogenic neutron veto
30 ton borated liquid scintillator
(LSV)

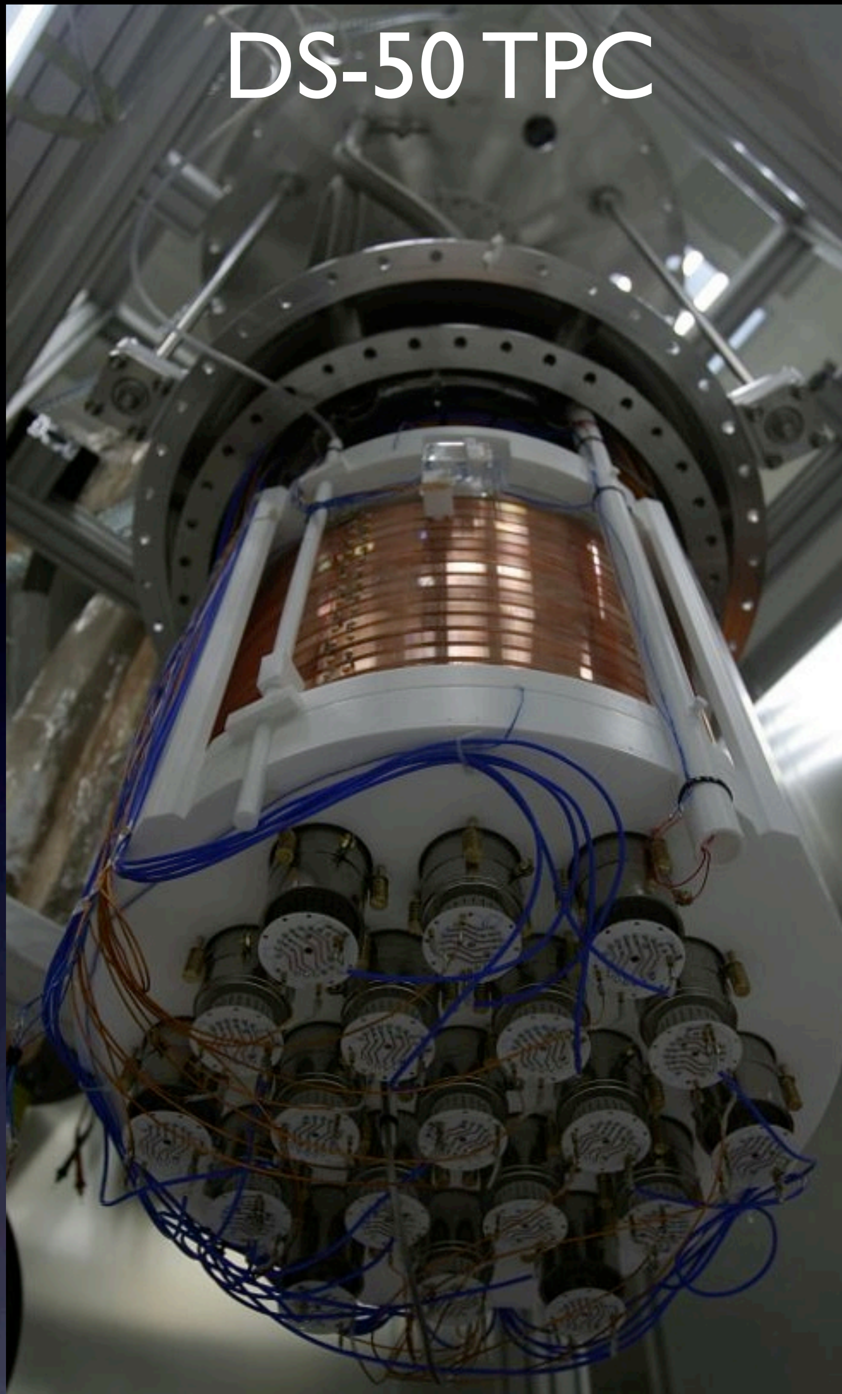
WIMP LAr detector
150 kg of UAr < 6.5mBq/kg
(DS-50 TPC)

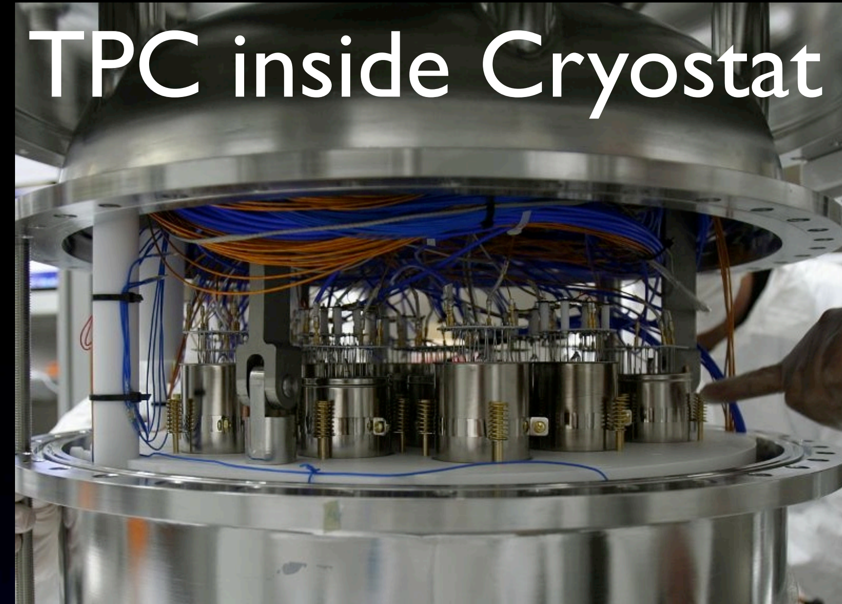
DarkSide design



- Class 10-100 clean room above Water Tank
  - ✓ Obtained Rn <30 mBq/m^3 in >100 m^3
- Ar recirculation and purification system
  - ✓ Cooling power 300 W
  - ✓ max rec. speed ~ 75kg/day







DS50-TPC Assembled, Deployed

TPC hanging in LSV

Water Tank & Liquid Scintillator Vessel with TPC umbilicals

DS-50 first test run

- ✓ Argon cooling, circulation, and purification system operated
- ✓ PMTs operated in liquid argon
- ✓ TPC Trigger and DAQ operated
- ✓ HV system operated at required field
- ✓ Dual phase operation achieved
- ✓ Pre-amps on PMT base (in-liquid) tested
- ✓ Remote levelling exercised

DS-50 second test run

- Replace bad PMTs
- Instrument all PMT bases with in-liquid pre-amps
- Install super-low radioactivity silica windows
- Fix weak points in the HV system
- Fix some heat leaks in the argon transfer lines
- Continuing improvements to theTrigger and DAQ

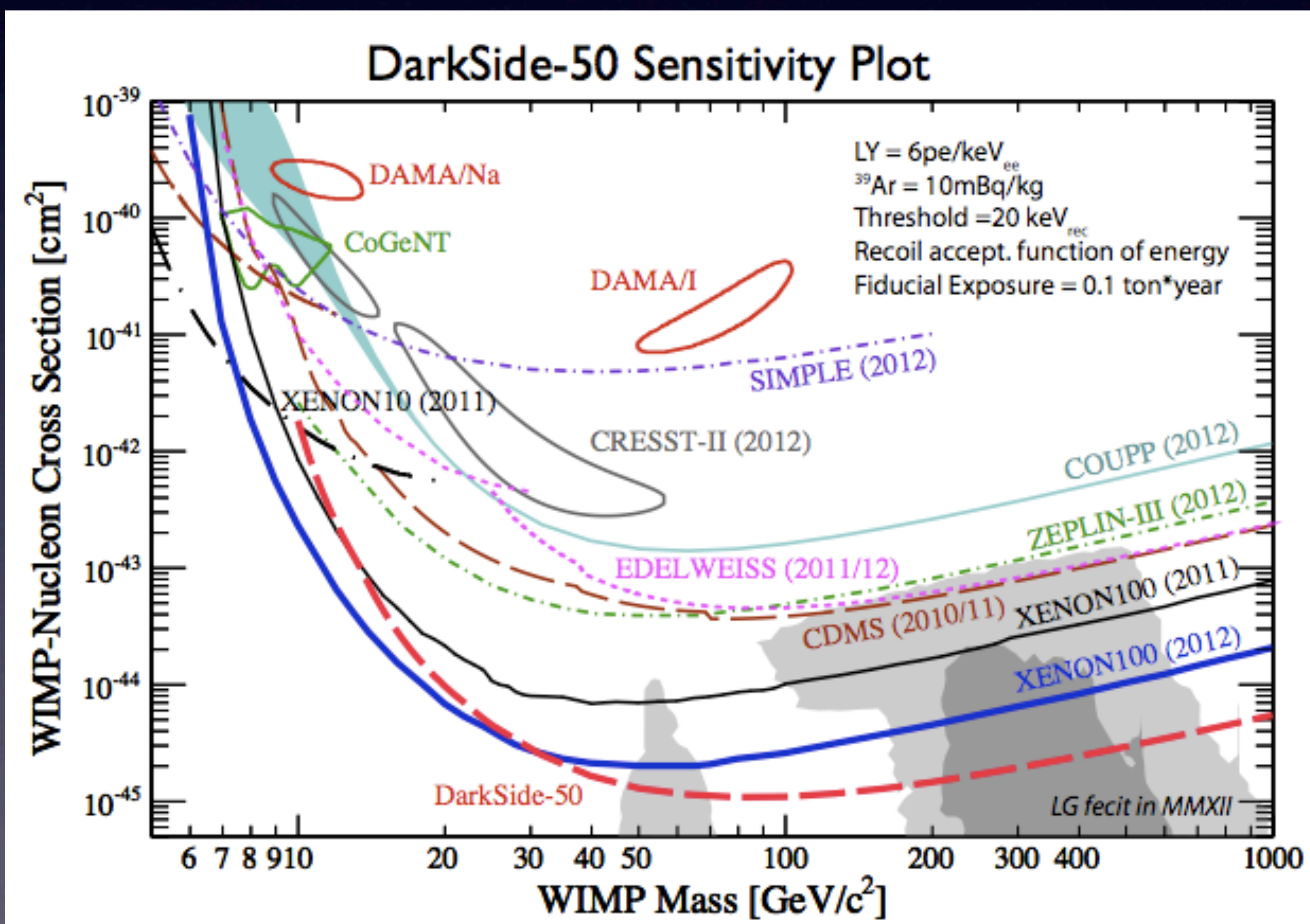
DS-50 Schedule

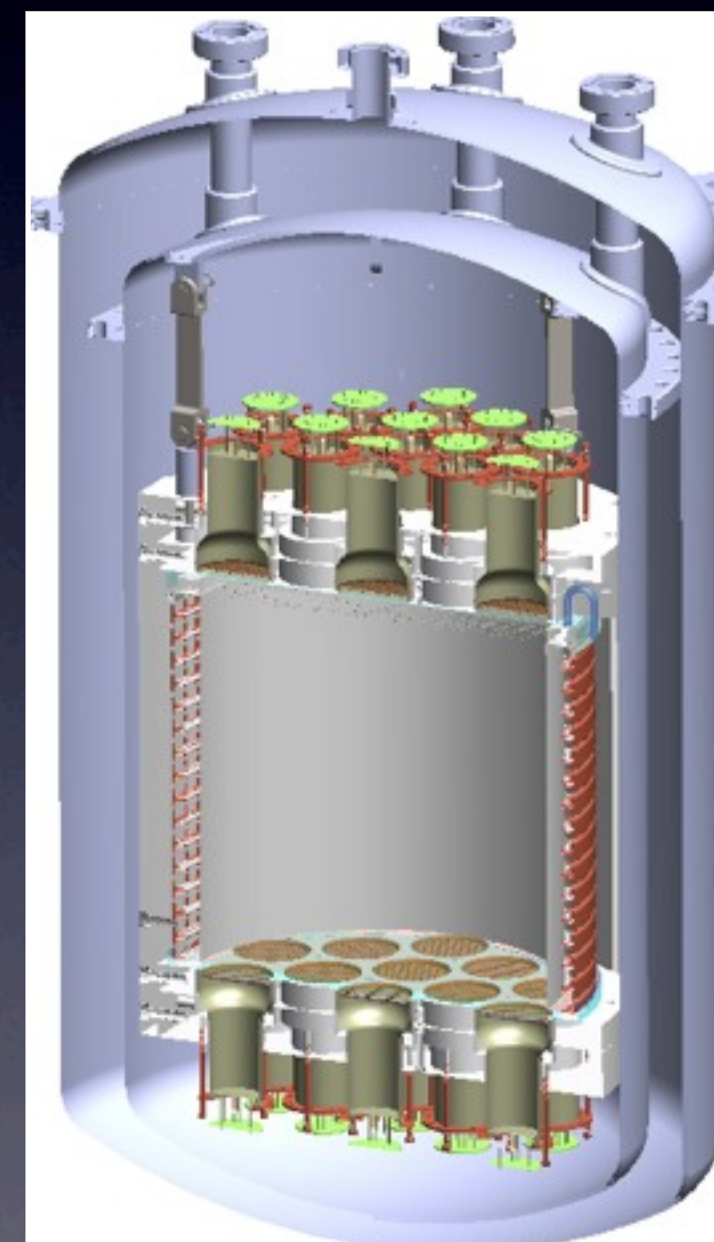
- 1st TPC test run (atm argon) ended June
- 2nd TPC test run starting now (atm argon)
- Fill Neutron Veto and Water Tank by end September
- Concentrate on background rejection performance
- Low radioactivity underground argon towards end of year

DS-50 projected sensitivity

$\sigma = 1 \times 10^{-45}$ cm^2 @ 100 GeV/c^2
0.1 ton x year exposure

Active: 50 kg
Fiducial: 33 kg

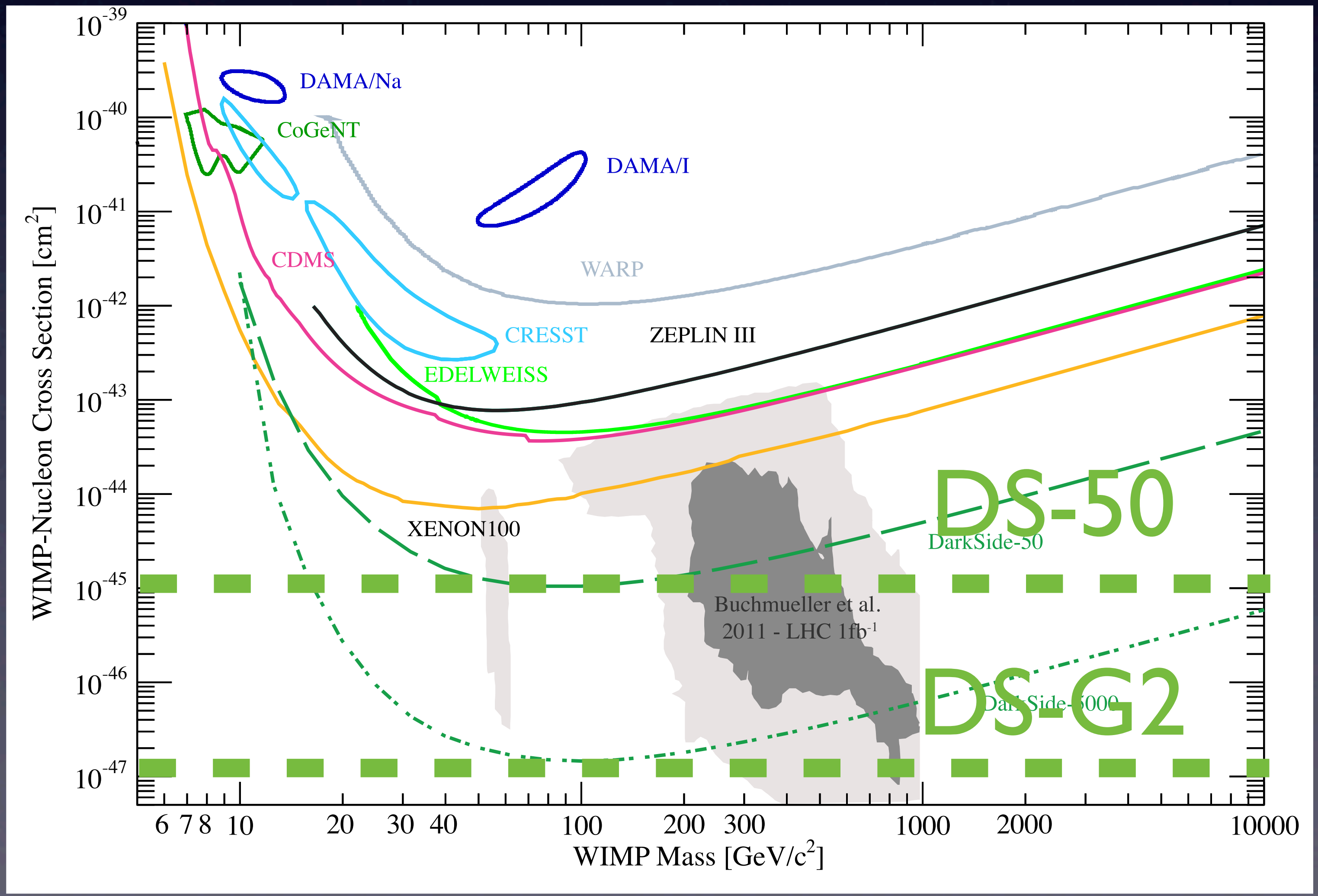


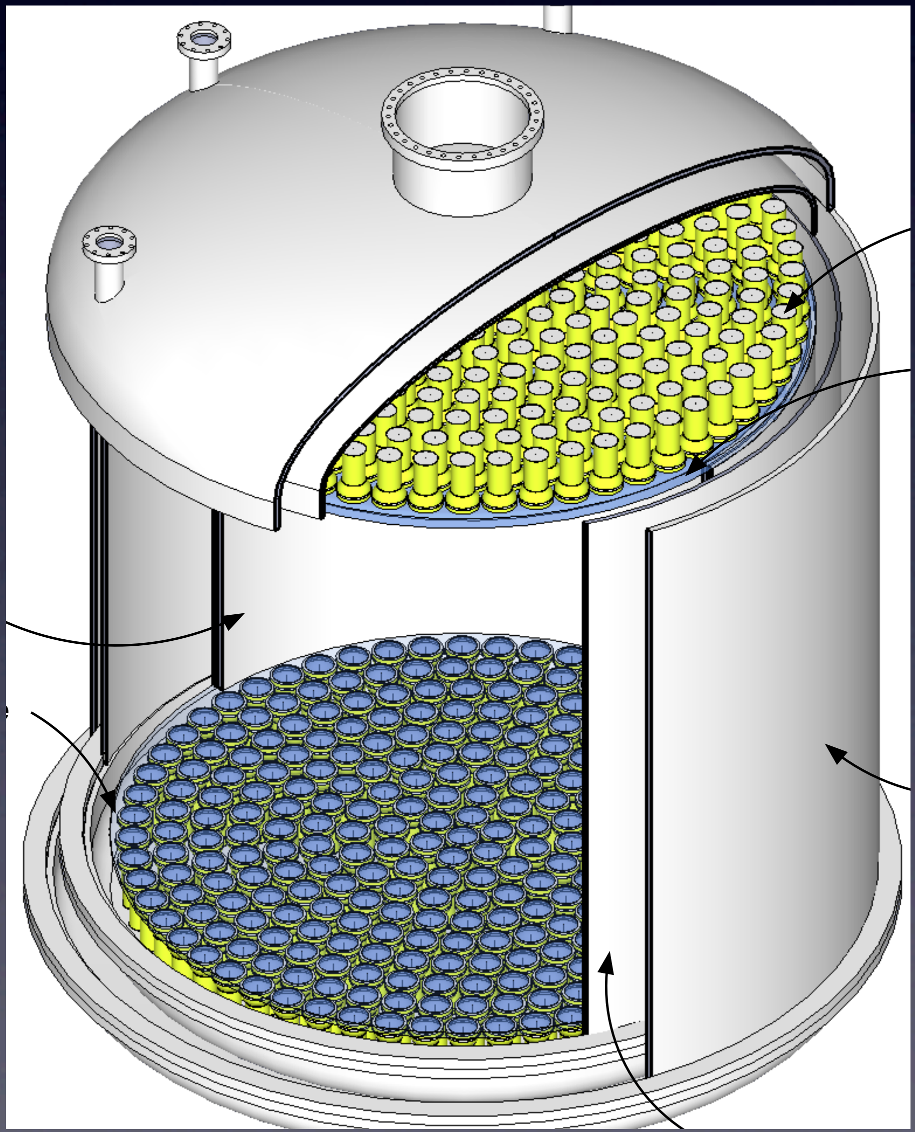


DS-G2 projected sensitivity

$\sigma = 1 \times 10^{-47}$ cm^2 @ 100 GeV/c^2
14 ton x year exposure

Total: 5 ton
Fiducial: 2.8 ton





Summary

DarkSide is a project for direct detection of dark matter with underground argon. The DarkSide-50 experiment at LNGS has a projected sensitivity of 10^{-45} cm^2.

DarkSide-50, is in the commissioning phase. The detector is housed in a 30-ton liquid scintillator neutron veto, which is in turn housed within a 1,000-ton water Cherenkov muon veto.

The underground argon is collected from a special well in Colorado. The DarkSide collaboration recently demonstrated that ^{39}Ar activity from the underground argon is less than 0.65% of the activity in atmospheric argon (corresponding to a reduction factor greater than 150.)

The DarkSide collaboration is also considering a proposal for a second generation detector, DarkSide-G2, with an active mass of 5 tons of underground argon. The sensitivity goal for DarkSide-G2 is 10^{-47} cm^2. DarkSide-G2 can be housed within the same neutron veto and cosmic muon veto already under construction for DarkSide-50.

Thank you.